AD-A157 566 RADIATION-PROTECTION SURVEY GUIDE: FIXED RADIOGRAPHIC UNIT(U) SCHOOL OF AEROSPACE MEDICINE BROOKS AFB TX R L WEED ET AL. MAY 85 USAFSAM-TR-85-17 1/1

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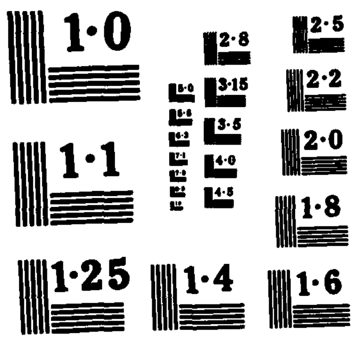

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USAFSAM-TR-85-17

RADIATION-PROTECTION SURVEY GUIDE: FIXED RADIOGRAPHIC UNIT

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May 1985

Final Report for Period June 1980 - April 1985

Approved for public release; distribution is unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, TX 78235-5301

NOTICES

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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Availability Codes	
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SECURITY CLASSIFICATION OF THIS PAGE

AD-A157566

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): USAFSAM-TR-85-17

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION: USAF School of Aerospace Medicine

6b. OFFICE SYMBOL *(If applicable)*: RZB

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS *(City, State and ZIP Code)*: Aerospace Medical Division (AFSC) Brooks AFB TX 78235-5301

7b. ADDRESS *(City, State and ZIP Code)*

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: USAF School of Aerospace Medicine

8b. OFFICE SYMBOL *(If applicable)*: RZB

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State and ZIP Code)*: Aerospace Medical Division (AFSC) Brooks AFB TX 78235-5301

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
62202F	SUPT	XH	PS

11. TITLE *(Include Security Classification)*: Radiation-Protection Survey Guide: Fixed Radiographic Unit

12. PERSONAL AUTHOR(S): Weed, Ronald L.; Jordan, Donald

13a. TYPE OF REPORT: Final

13b. TIME COVERED: FROM Jun 80 TO Apr 85

14. DATE OF REPORT *(Yr., Mo., Day)*: 1985 May

15. PAGE COUNT: 21

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB. GR.
18	06	

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*

X-ray machine survey,
Medical Radiographic Unit,
Radiation protection.

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Prior to routine use, all newly installed x-ray machines must have a radiation-protection survey by a qualified expert. The survey is an evaluation of existing or potential radiation hazards associated with the use of diagnostic x-ray equipment under specific conditions. Such evaluation includes the measurements of exposure levels in the environment as well as environmental levels arising from operation of the equipment. The survey also includes an evaluation of the safety characteristics of the x-ray unit. Originator supplied keywords include:

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT

UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: R. L. WEED, Captain, USAF

22b. TELEPHONE NUMBER *(Include Area Code)*: (512) 536-3416

22c. OFFICE SYMBOL: USAFSAM/RZB

DD FORM 1473, 83 APR

EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

RADIATION-PROTECTION SURVEY GUIDE: FIXED RADIOGRAPHIC UNIT

INTRODUCTION

A radiation protection survey as used here is an evaluation of a diagnostic medical x-ray unit. It is a report of output exposures at different mA's, kVp's, and durations; leakage; and scatter. It is a check on alignment of the collimation. It may also include a checklist of safety practices and exposures at different routine techniques. Finally, a radiation-protection survey of diagnostic x-ray practices can tell us if work practices are exceeding the designed shielding in the walls and barriers and if existing distances to technicians/general public are sufficient. Most important, it can tell us if exposure to a patient can be reduced.

The Air Force requires a radiation protection survey of all new fixed x-ray units, and those not previously surveyed, before the unit is routinely used. The surveyed unit must meet Federal, U.S. Air Force, and Joint Commission on Hospital Accreditation requirements. The survey must be made by a qualified expert and must be made at least once every 3 years and after every change in equipment, workload, or operating condition that might significantly increase the chance of someone receiving exposures in excess of the radiation protection standard. The Air Force survey report should include the following information:

1. X-ray tube leakage

2. Total filtration and beam quality

3. Beam collimation and alignment

   a. Numerical indication of beam size
   b. X-ray field/image receptor alignment
   c. X-ray/light-field alignment

4. Current (mA) linearity and reproducibility

5. Timer accuracy and reproducibility

6. Radiation output

7. Shielding and scatter measurements

X-RAY TUBE LEAKAGE

Regulation and guidance:* A diagnostic-type protective tube housing shall be used. A diagnostic-type protective tube housing is defined in 21 CFR

*Regulations and other guidance documents cited in the text are listed at the end of the text.

and NCRP #33 as "an x-ray tube housing so constructed that the leakage radiation measured at a distance of 1 meter from the target cannot exceed 100 mR in 1 hour when the tube is operated at its maximum continuous rated current for the maximum rated tube potential" (21 CFR 1020.30,31). Compliance is determined by averaging measurements over an area of 100 cm^2 with no linear dimension greater than 20 cm.

Equipment Required

1. Ionization-chamber-type survey meter having a short response time (e.g. 1-3 s) and a 100-cm^2 probe. An MDH (a survey instrument manufactured to U.S. Government specifications by MDH Industries, Monrovia, CA) or integrating survey meter is suitable for table measurements. Most survey meters are suitable if response time and sensitivity are adequate.

2. Fluorescent strips approximately 1" x 8" (~2.5 x 20.3 cm) or a fluorescent square approximately 6" x 6" (~15 x 15 cm). (See Figure 1.)

3. Lead sheet, 0.125" (~0.32 cm) thick, with 2" x 2" (~5 x 5 cm) aperture.

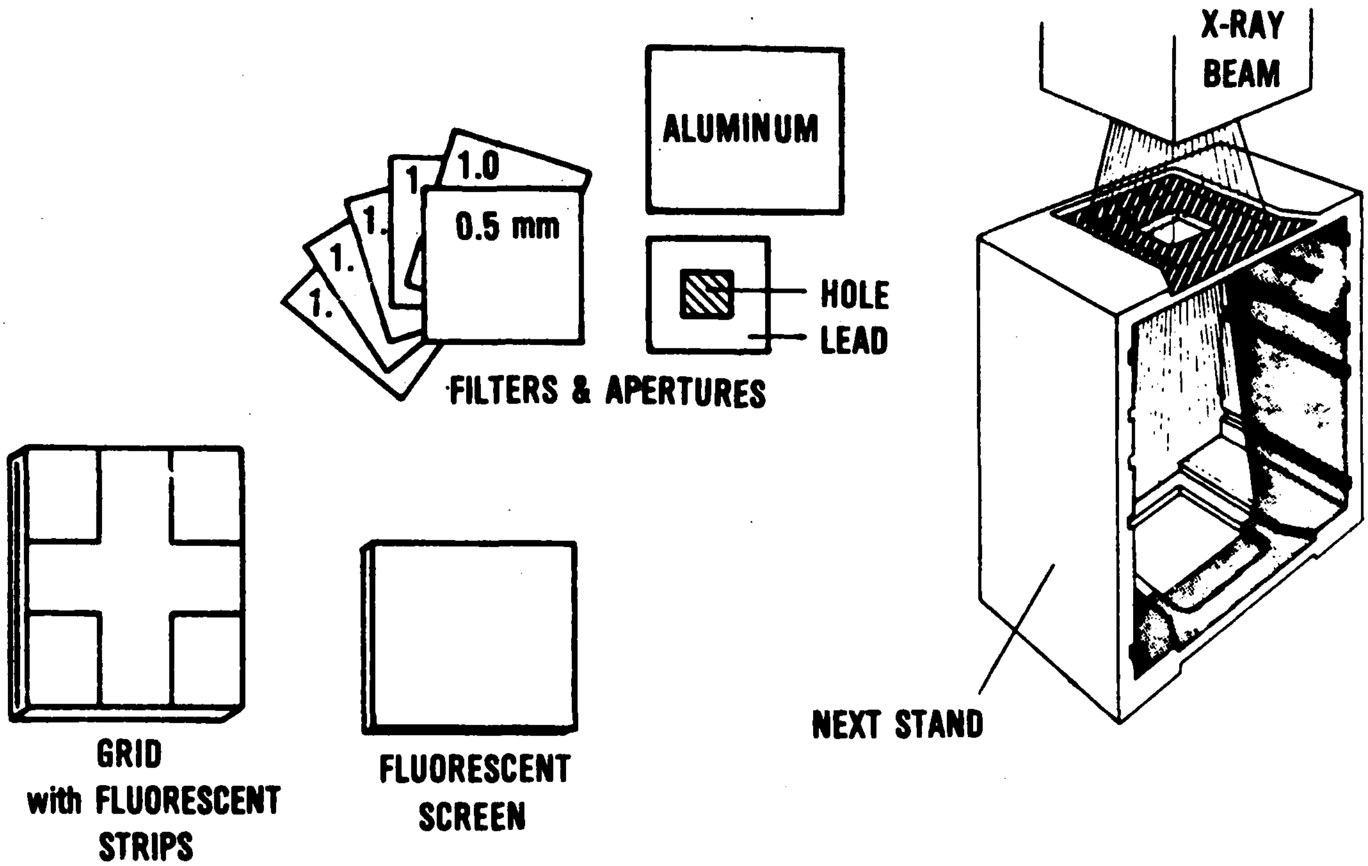


Figure 1. Survey equipment.

Procedure

1. Completely close beam-limiting device (BLD) or adjust to the minimum field size. Block the BLD with at least 1.0 half-value layer (HVL) of lead.

2. Set a medium kVp, low mA, and 3-s technique.

3. Place (or affix) fluorescent strips/sheets over each side of the diagnostic source assembly (so any leakage will fluoresce on the strips/sheets).

NOTE: Surveyor should wear a lead apron when not behind the x-ray operator's protective barrier during exposures.

4. Darken the room and take sufficient exposures to observe if there are any visible pinpoints of light which could signify leakage radiation. (An assistant makes the exposures.) If so, the amount of leakage should be quantitated using the following procedure:

a. Set the x-ray unit's maximum rated kVp and set a time approximately equal to the response time of the survey meter to be used (e.g. 2-3 s).

b. Do not allow the technique's heating rate to exceed the tube anode's cooling rate. See NOTE below.

c. Position survey meter 40" (~1.2 m) from the tube target in line with the suspected leakage.

d. Make sufficient exposures (e.g. 3-4) and average over an area of approximately 100 cm^2.

e. Calculate the exposure rate for continuous operation by multiplying the exposure rate obtained in step d by the ratio of the mA for continuous operation to the mA used for the measurement (Calculation 1 in Appendix).

NOTE: The maximum continuous rated current for the maximum rated tube potential is a function of the anode cooling rate for the particular x-ray unit under survey. The anode cooling rate for various tube models and manufacturers is available at the user's facility and should be checked to determine that exposures made during the survey do not exceed the machine's anode cooling rate.

TOTAL FILTRATION AND BEAM QUALITY

Regulation (AFM 161-38): The aluminum equivalent of the total filtration of the useful beam shall not be less than the following:

Maximum tube potential	Minimum total filtration
below 50 kVp	0.5 mm Al
50 to 70 kVp	1.5 mm Al
above 70 kVp	2.5 mm Al

In some cases the x-ray unit's added filtration can be removed and its thickness measured. The total filtration in the beam is the sum of the added and inherent filtration. If the inherent filtration is not known, then 0.0-mm Al may be assumed (i.e. zero filtration).

If the amount of filtration cannot be visually inspected, then a HVL determination must be made. The aforementioned filtration criteria may be assumed to have been met if the HVL corresponding to the kVp used for the measurement is not less than the values contained in Table 1.

TABLE 1. MINIMUM HVL AS A FUNCTION OF kVp*

kVp	50	60	70	80	90	100	110	120
HVL Al	1.25	1.42	1.59	2.35	2.58	2.82	3.06	3.30
**	1.2	1.3	1.5	2.3	2.5	2.7	3.0	3.2

*In a machine with full-wave rectified potential.
**From AFM 161-38, Atch 2, Table 2.
NOTE: Taken from NCRP Report No. 33, Appendix B, Table 3.

The following equipment is needed to make an HVL determination, and the listed procedures should be followed.

Equipment Required

1. Radiation detector (low to medium energy): either a direct reading dosimeter or an ionization chamber with the detection area dimension not greater than 3" (~7.6 cm) and having a means suitable to read the exposure (a probe/meter such as an MDH is satisfactory)

2. Measuring tape such as a common tape rule

3. Five 4" x 4" (~10 x 10 cm) by 1.0-mm aluminum type 1100 alloy sheets

4. One 4" x 4" by 0.5-mm aluminum type 1100 alloy sheet

5. NEXT stand with one lead 4" x 4" plate with 2" x 2" hole (See Figure 1). (A Nationwide Examination of X-ray Trends [NEXT] stand was constructed by the Center for Devices and Radiological Health, Washington, DC).

Procedure

1. Position radiation detector in the approximate center of the x-ray field. (See Figure 2.)

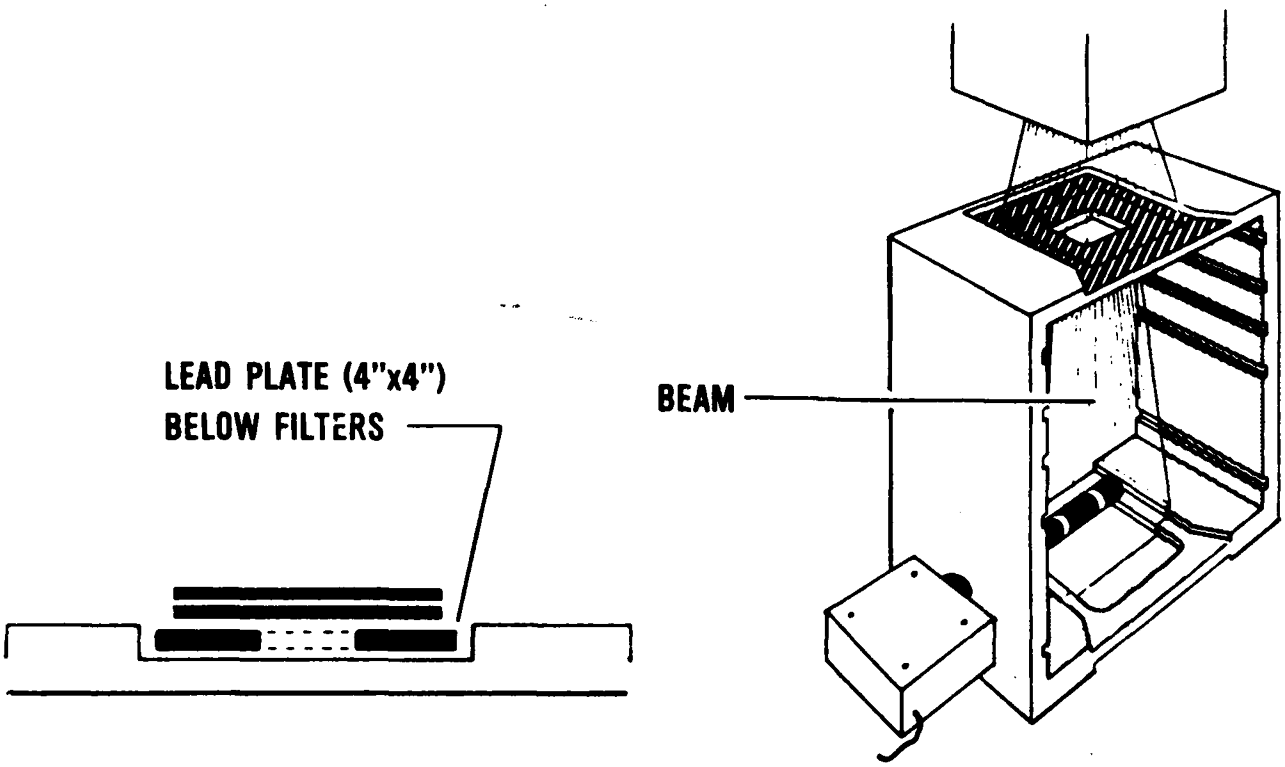


Figure 2. NEXT stand setup

2. Select an appropriate technique (kVp and mAs) to obtain a reading of approximately two-thirds detector full-scale deflection (e.g. 90 kVp, 100 mA, and .1 s at 40" to tabletop). The NEXT stand has a slot for the MDH probe at 3.75" (~ 9.5 cm) above the tabletop.

3. Expose the detector and record the measurement.

4. Place a 1.5-mm Al sheet between the x-ray tube head and the detector. (Place the aluminum in the slot at the top of the NEXT stand.)

5. Using the same technique factors, again expose the detector and record the measurement.

6. Add an additional 1.0-mm Al to the other sheet and repeat steps 4 and 5 until a measurement less than or equal to one half the initial measurement recorded in step 3 is obtained.

7. Calculate HVL.

BEAM COLLIMATION AND ALIGNMENT

Regulation (AFM 161-38, 9b(1)(b)): Suitable collimating devices (adjustable diaphragms or auto collimators) capable of restricting the useful beam to the area of clinical interest shall define the beam and provide the

ıme degree of attenuation as required of the tube housing. Such devices ıall be calibrated in terms of the size of the projected useful beam at the ›ecified source-film distance. For chest photofluorographic equipment, the ›llimator shall restrict the beam to dimensions no greater than those of the .uorographic screen.

Radiographic equipment, particularly multipurpose x-ray units, shall be ıuipped with adjustable rectangular collimators containing light localizers ıat define the entire field. Automated rectangular collimators are 'eferable. All multipurpose x-ray units shall have a filter system that learly indicates the amount of added filtration in place. Adequate ›llimation and alignment on the developed x-ray films must be visibly ıdicated.

Numerical Indication of Beam Size

Regulation (AFM 161-38, 9b(2)(b)): The beam-limiting device shall indi- ıte numerically linear dimensions of the x-ray field of the source-to-image lstance (SID) for which it is designed. Such indications shall not deviate 'om the actual dimensions of the x-ray field at the SID by more than 2% of ıe SID when the equipment indicates that the axis of the primary beam is ›rpendicular to the plane of the image receptor (i.e. at a SID of 40", the lze of the x-ray image cannot be greater than .8" [2% x 40"]). Also, the ›am defining the light field shall be aligned with the x-ray field to within ℓ of the SID.

ıuipment required

1. Loaded 10" x 12" (~25.4 x 30.5 cm) cardboard cassette

2. Measuring tape such as a common tape rule

rocedure (See Figure 3.)

1. Adjust the x-ray tube head assembly so that it is approximately ›ntered over the tabletop.

2. Center the loaded cardboard cassette under the x-ray tube. Place ırdboard on tabletop directly above the bucky cassette.

3. Select a suitable field size at the approximate source-to-tabletop lstance (STTD), e.g. 40".

4. Set a kVp, low-mAs technique (e.g. 90kVp, 10 mAs, 40").

5. Expose and develop the film.

6. Measure the field size on the film. The linear dimensions of the -ray field should not deviate from the selected beam size by more than 2% of ıe SID.

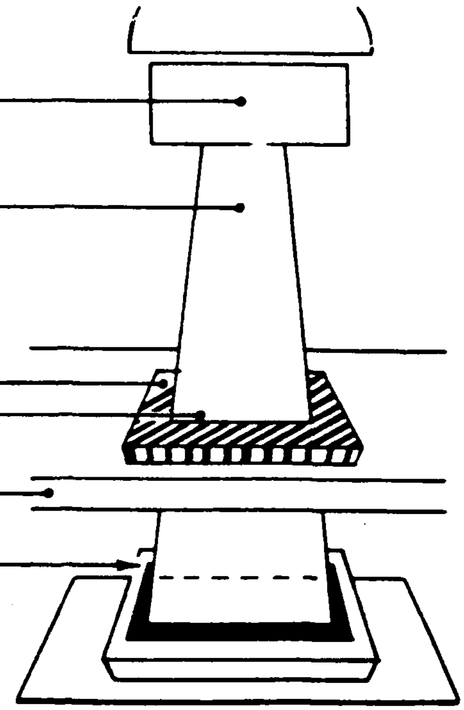


Figure 3. Equipment setup for checking collimation field alignment.

X-ray Field/Image Receptor Alignment

Regulation (AFM 161-38, 9b(2)(b)): The alignment of the center of the x-ray field with the center of the image receptor shall be indicated to within 2% of the SID.

Equipment Required

1. Loaded cardboard cassette (e.g. 10" x 12")

2. Markers (e.g. pennies or paper clips)

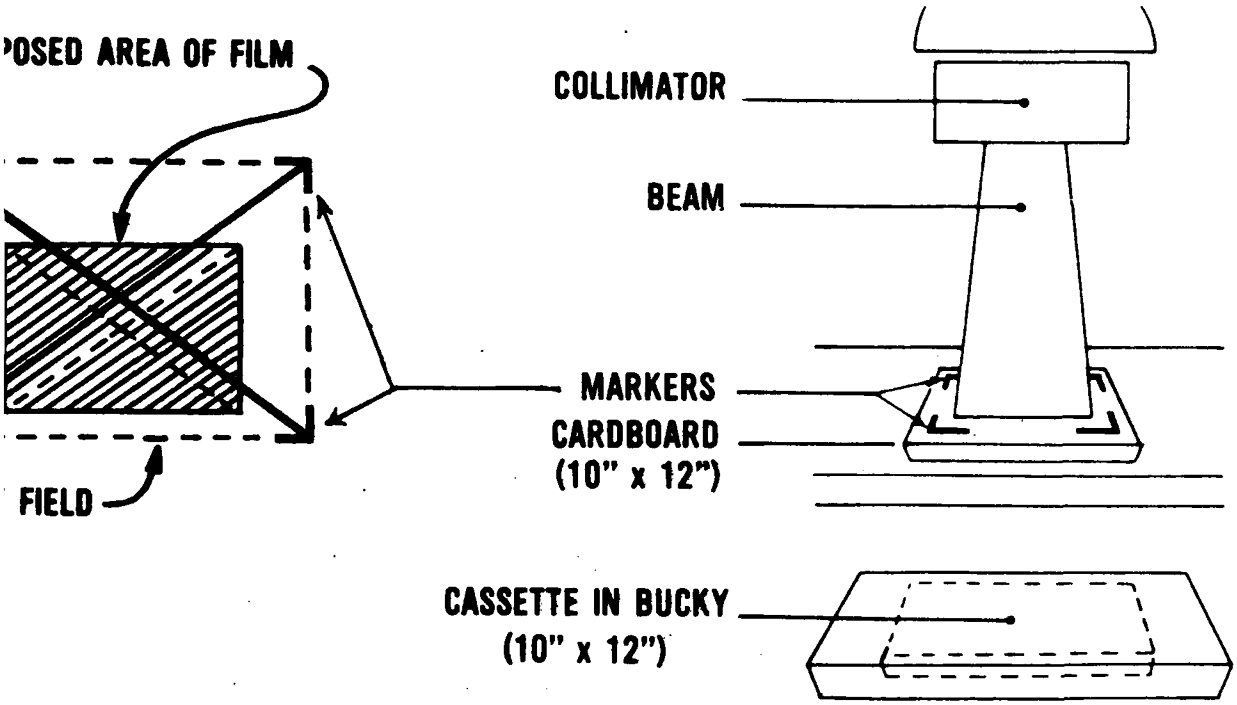
3. Straightedge and tape measure

Procedure (See Figure 4.)

1. Position the tube head assembly over the approximate center of the x-ray table. Assure that x-ray beam is perpendicular to image receptor.

2. Load cassette into bucky tray and place the markers on the corners of the cardboard cassette's light field.

3. Center the bucky tray beneath the x-ray tube. Make certain that the proper alignment is achieved.



igure 4. Arrangement of markers for checking collimator field alignment.

4. Select a medium kVp, low-mAs technique (80 kVp, 10 mAs, 40" to bucky ette). Expose and develop the film.

5. Delineate the x-ray field on the film and determine the field's er.

6. Measure the linear displacement or misalignment of the center of the ;e rceception and x-ray field.

7. Determine the SID and calculate to 2% SID.

8. Total misalignment should be less than or equal to 2% SID for compli- with this regulation (e.g. at 40" SID x 2%, misalignment must be less than . (See Figure 5.)

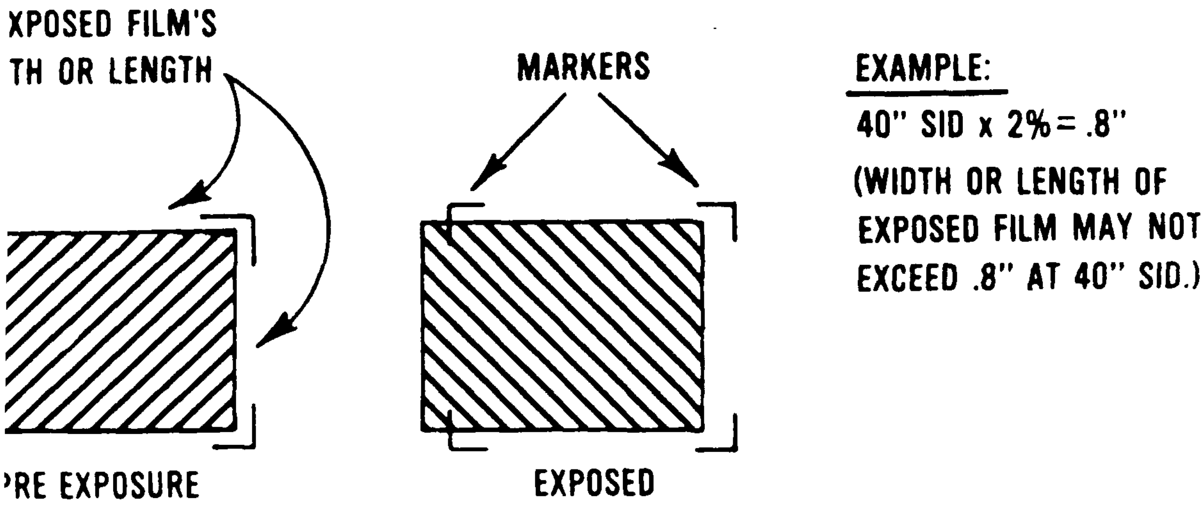


Figure 5. Example of correctly placed marker (preexposure) and exposed field measurement.

X-ray/Light-Field Alignment

Regulation (21 CFR 1020.31(e)(2)(ii)): The x-ray field size in the plane the image receptor, whether automatically or manually adjusted, shall be :h that neither the length nor the width of the x-ray field differs from it of the image receptor by greater than 3% SID (i.e. the width or length of : x-ray field cannot be greater than the marked (light indicated) field by ·e than 3% SID).

ıipment Required

1. Loaded cardboard cassette
2. Four metal markers (pennies or paper clips)
3. Measuring tape

ocedure

1. Position the x-ray assembly over the approximate center of the oletop.

2. Center the loaded cassette on the tabletop under the tube head.

3. Select a suitable light-field size (e.g. 10" x 12") and position the ter edge of each metal marker to correspond with each side of the light eld. (See Figure 4.)

4. Select a kVp, low-mAs technique (e.g. 90 kVp, 10 mAs at 40" to the cky cassette). Expose and develop the film.

5. Compare the edges of the x-ray field with the edges of the light field as defined by the outer edges of the metal strips. Misalignment is determined by measuring the separation between the x-ray field and the outside edge of the image of the respective metal marker.

6. Total misalignment in the length and width dimensions is the sum of the measured separations for opposite sides of the x-ray field.

7. Determine SID and calculate 3% SID. Both the length and the width misalignments should be less than 3% SID.

NOTE: The sum of the misalignment (either + or -) of the width and the length shall not exceed 4% SID (i.e. if the widths are off by .8" and the lengths off by .9", then the sum [1.7"] is greater than 4% SID [4% of 40" = 1.6"]; the collimator is misaligned).

EXPOSURE LINEARITY AND REPRODUCIBILITY

NOTE: The measurement of current (mA) linearity is performed indirectly by measurement of two adjacent mA stations (four exposures each). (See Calculation 2, Appendix.)

Regulation AFM 161-38, 9b(2)(h)): When the x-ray unit is equipped with tube current (mA) selectors, the exposure rate will increase proportionally with an increase in mA. The measured values shall not deviate more than 10% when all factors (kVp, length of exposure, and distance) are kept constant.

Regulation (21 CFR 1020.31 (c)(1)): The average ratios of exposure to the indicated milliampere-seconds product (mR/mAs) obtained at any two consecutive tube current settings shall not differ by more than 0.10 times their sum.

Equipment Required

Radiation detector (low or medium energy): either a direct-reading dosimeter or an ionization chamber with a detection area dimension not greater than 3" (~ 7.6 cm) and having a suitable means of reading exposures. An MDH in a NEXT stand is suitable.

Procedures

1. Position radiation detector in the center of the radiation beam. Collimate the beam to include only the active area of the radiation detector. Use a NEXT stand if available.

2. Set a kVp and a low mAs technique (e.g. 90 kVp, .1 s, 40" STTD). (See Figure 6.)

3. Expose the detector and record the measurement.

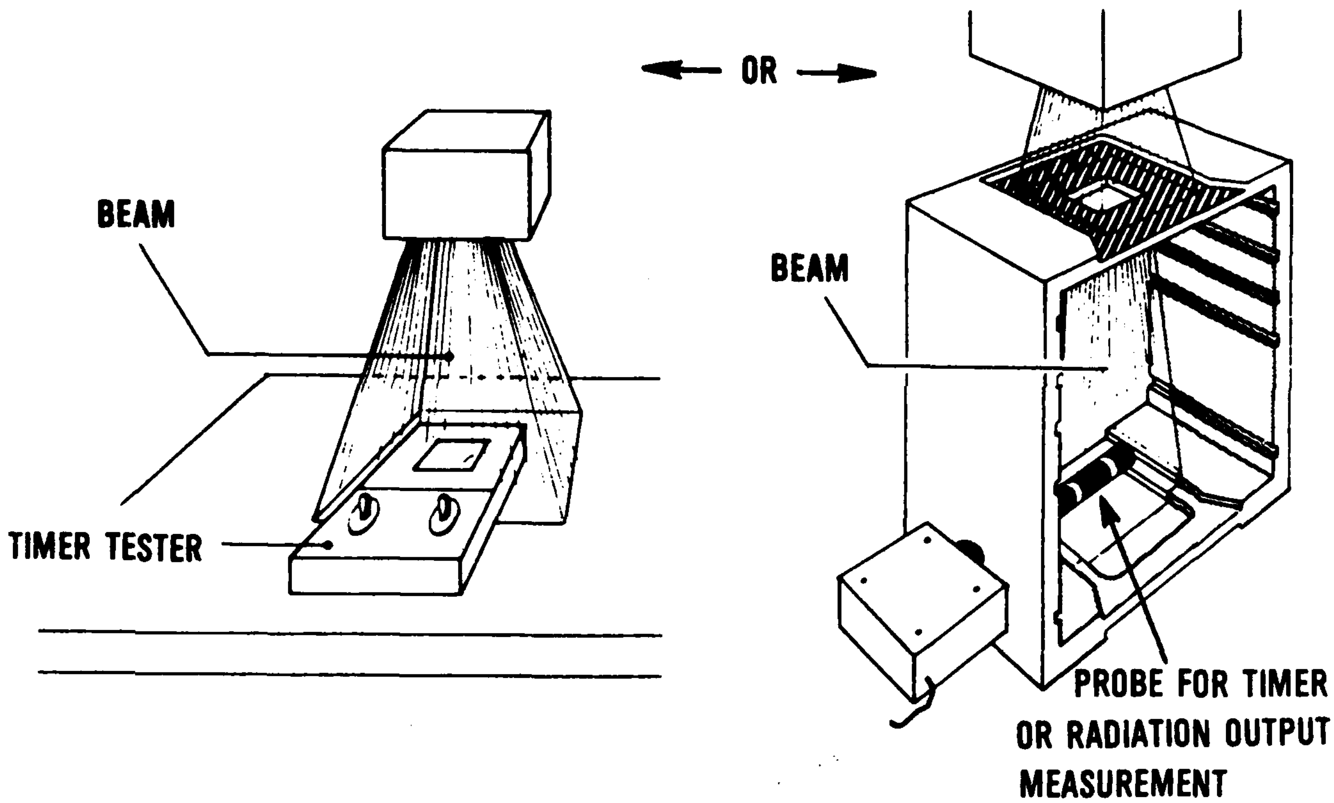


Figure 6. Arrangement of timer device (when used alone) and MDH probe (for measurement of both time and radiation output).

4. Increase mA to the next highest station. Maintain kVp, exposure time, and source-to-detector distance constant.

5. Again expose the detector and record the measurement for 10 mA stations. Calculate the average mR/mAs for each mA station. All mR/mAs values must be within 10% of average.

6. If the MDH is used, be sure that the meter is measuring exposure, not duration; that proper barometric pressure is included; and that pulse-fraction threshold for single or three phase has been selected.

7. For reproducibility check, expose detector at two adjacent mA stations for four exposures at each station, moving from one mA to the other. (See Calculation 2, Appendix.)

8. To check linearity, take the average mR/mAs value at the first adjacent mA station (Y_1) and the second mA station (Y_2) and solve for linearity (d) in Calculation 3 (Appendix).

Timer Accuracy and Reproducibility

Equipment Required

An x-ray timer tester or the MDH 1015

NOTE: The MDH set on pulse duration may be used with accuracy down to .05 s. An x-ray timer tester is an instrument capable of quantitating x-ray "on" time through measurement of exposure time in a silicon diode or ionization chamber. The instrument possesses two modes of operation which permit the verification of timer accuracy of both single- and three-phase x-ray units.

Procedure

1. The timer tester uses the pulse-counter mode for timer tests of single-phase, and uses the other mode for three-phase units (or for constant potential). Follow precisely the specified procedures supplied with any of the commercially available instruments.

2. The MDH is suitable for timer measurements; at very low time settings (below .05 s), however, greater than 10% discrepancy may be observed. Select the pulse-fraction threshold (PFT) appropriate for a single- or three-phase machine; (usually the PFT is .2 for single phase, .5 for full phase); also, select the duration setting.

3. Expose detector to 10 exposures beginning at the lowest normally used timer station. Continue upward, increasing time generally by double the previous number.

4. For reproducibility, choose one typical timer setting and repeat exposures four times in succession. Calculate average time and then calculate the coefficient of variation. (See Calculation 4.)

Radiation Output

NOTE: Although measurement of kVp output is not required, exposure variation may indicate problems if exposures do not increase in relation (logarithmic) to increases in kVp.

Equipment Required

Same as for mA linearity and reproducibility

Procedure

1. Set mA at 100 and time at .1 s, distance at 40" to tabletop.

2. Ten exposures are made from lowest normally used kVp to highest (e.g. 40 to 120 kVp).

3. Calculate mR/mAs and observe irregularities. A normal increase should occur with regular kVp increases.

Shielding and Scatter

Regulation (AFM 161-38, 3a,b,c, and d). The radiation survey includes inspection of the equipment, examination of its location with reference to controlled and noncontrolled areas in the immediate environment, and measurements of exposure levels in the environment arising from operation of the equipment (also see AFM 161-38, 7a through b).

Equipment required

A survey instrument with suitable response and sensitivity, e.g. Victoreen 440, 471A, 470; an Eberline or Keithley Survey Meter may also be suitable.

Procedure

1. From available wall plaques or direct measurement, record shielding existing in walls.

2. Sketch prominent features of room such as table, barrier, wall-chest cassette holder, doors, generator. Indicate "north" and direction of tube head during scatter survey.

3. Record scatter technique. Include kVp, mA, time, phantom type, STTD, and field size. Use highest tube potential and tube current at which the unit typically operates and at tube-to-phantom angle that will provide the greatest amount of scatter radiation at the point of interest.

4. Survey walls of room, windows, doors, baffles, cracks, holes, ceiling (only in unusual situations), lead windows in shielding/barriers, and hall with door open (if open door is normal). Ask the question, "Where does technician, doctor, general public usually stand?"

5. Place phantom on table or wall-chest cassette holder. Collimate to the largest field size. Indicate the direction of beam on the sketch.

6. In evaluating the results of the survey, consider the actual operating conditions, including workload, use factor, occupancy factor, and attenuation of the useful beam provided by patients and objects permanently in the path of the useful beam.

REGULATIONS CITED

21 CFR 1020.30,31 -- Code of Federal Regulations. A codification of documents of general applicability and future effect as of 1 April 1982. Office of the Federal Register, National Archives and Records Service, General Services Administration, U.S. Government Printing Office, Washington, DC, 1982.

NCRP 33 -- National Council on Radiation Protection and Measurements. Medical x-ray and gamma ray protection for energies up to 10 MeV. Equipment design and use. Bethesda, MD, 1968.

Air Force Manual 161-38. Aerospace medicine diagnostic x-ray, therapeutic x-ray, and gamma-beam protection for energies up to 10 million electron volts. Department of the Air Force, HQ USAF, Washington, DC, 12 Oct 1973.

APPENDIX

CALCULATIONS FOR LEAKAGE MEASUREMENT, EXPOSURE LINEARITY, mA REPRODUCIBILITY, AND TIMER REPRODUCIBILITY

CALCULATION 1: LEAKAGE MEASUREMENT CALCULATED AT CONTINUOUS mA OPERATION

$$\text{Corrected exposure} = \text{Measured exposure} \times \frac{\text{mA for continuous operation}}{\text{mA used for measurement}}$$

CALCULATION 2: CALCULATION FOR mA REPRODUCIBILITY

NOTE: Choose two consecutive mA stations and repeat exposures, alternately between the two stations, four exposures each. Calculate the average exposure of each mA station and calculate the coefficient of variation for each (C_1 and C_2):

$$C = \frac{1}{mRav} \sqrt{\frac{\text{Sum } (mRi - mRav)^2}{3}}$$

NOTE: C_1 and C_2 must be equal to or less than 0.05.

Where mRi = exposure at mA station

mRav = average of four measured mA exposures

CALCULATION 3: CALCULATION OF EXPOSURE LINEARITY AT TWO mA STATIONS

Calculate the difference of the average exposures at two stations (Y_1 and Y_2)

$$d = \left| \frac{Y_1 - Y_2}{Y_1 + Y_2} \right|$$

NOTE: d (difference) must be less than or equal to 0.1.

CALCULATION 4: CALCULATION FOR TIMER REPRODUCIBILITY

NOTE: Choose one typical timer setting and repeat exposure four times in succession. Calculate average time and then calculate the coefficient of variation (C):

$$C = \frac{1}{mTav} \sqrt{\frac{\text{Sum } (Ti - Tav)^2}{3}}$$

NOTE: C must be equal to or less than .05

Where Ti = timer setting

Tav = time average of four measured times

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